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Mesophilic and Thermophilic Treatment of Distillery Wastewater: A Comparative Study

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Abstract

Distillery wastewater, generally known as spent wash, poses treatment and disposal problems due to its very high volume and strength. The present work on plant scale has been conducted to examine the treatment efficiency and biogas production during mesophilic and thermophilic anaerobic treatment of distillery wastewater from a batch fermentation based distillery under different HRT and organic loading rates. Mesophilic anaerobic treatment of spent wash was carried out in three UASB reactors R_1, R_2 and R_3 at 36 to 38 ^{0}C and at pH varying from 7.5 to 7.9. Thermophilic treatment was done in a down flow thermophilic reactor R_4 at 51.1 to 55.6 ^{0}C and pH of 7.67 to 7.89. Mesophilic treatment resulted in an average 66.4%, 62.6% and 66.5% COD removal for R_1, R_2 and R_3 at average loading rates of 15342, 15314 and 20806 kg COD/day and with average HRT of 9.1, 10.6 and 10.5 days, respectively. Average gas production was 16832 m^3/day at OLR of 16655 kg COD/day and HRT of 10 days for all three UASB reactors. Thermophilic treatment of spent wash in reactor R_4 registered an average 68.3% COD reduction at average loading rate of 76187 kg COD/day and HRT 15 days and average gas production was 29917 m^3/day with methane content of 59.8%. Sulphide concentration increased with increase in OLR and results in lower gas production as well as methane content.

Keywords: Distillery Wastewater, Anaerobic Treatment, Mesophilic Treatment, Thermophilic Treatment, Reactor, UASB Reactor, Spent Wash, Biogas, BOD, COD, Organic Loading Rate, HRT

Introduction

The fermentation industries including distilleries, breweries and malteries have posed serious environmental threat throughout the world (Gaur, 1990). There are about 285 distilleries in India producing 2.7 billion liters of alcohol and generating 40 billion liters of wastewater, known as spent wash, annually. The distillery wastewater has potential to produce 11 million cubic meter of biogas, annually. This biogas normally contains about 60% methane (CH_4), which is well recognized fuel gas with minimum air pollution (Joshi, 2000).

Spent wash is characterized by its dark brownish colour, high temperature, low pH and high percentage of organic and inorganic matter. It contain about 90-93% water, 7-10% solids, 2-20% sugar and 10-11% proteins (Joshi, 2000). Despite stringent standards imposed on effluents quality, the untreated or partially treated effluents very often find access to water courses and along the marginal lands surrounding the distilleries. Thus, the distillery wastewater poses a serious threat to air, water and land in several region of the country.

Although a number of treatment methods of spent wash have been developed i.e oxidation pond, activated sluge process, trickling filter, upflow sluge blanket reactor (UASB) etc., but no single method of treatment is considered appropriate for distillery waste treatment due to its high chemical oxygen demand (COD)/biological oxygen demand (BOD) and wide variation in characteristics. Reduction of COD/BOD of highly polluting distillery effluents is a challenging task. It has been reported that the cost of treatment of huge quantities of effluent discharge by the distillery is more than the capital cost of distillery itself (Joshi, 2000). If the spent wash utilization and by-product recovery is not economically feasible or has its own limitation, the biological treatment of spent wash is the only mean of disposal. Additionally, the liquor remaining after by-product recovery is not generally suitable for discharge to a receiving water body and requires further treatment. Distillery spent wash has COD to BOD ratio in the range of 1.8-2.0, which indicates that this wastewater is amenable to biological treatment (Kanhe et. al., 2003).

Anaerobic biological treatment processes are usually preferred for treating high strength organic waste such as those strong alcoholic distilleries, pulp and paper mills etc. mainly due to a very low operating cost and production of fuel in the form of methane as a by-product (Hall, 1992). Anaerobic treatment of wastewater is generally done by using following methods: anaerobic lagoon, anaerobic filter, anaerobic fixed film reactor (AFFR), up flow anaerobic sludge blanket (UASB) reactor, anaerobic thermophilic down flow reactor etc.

The up flow anaerobic sludge blanket process was developed in Netherlands in 1970s (Lettinga et. al., 1980). It has been used successfully for treatment of wide variety of aqueous effluents including wastes produce from breweries and distilleries (Hulshoff Pol and Lettinga, 1986; Ponlin, 1989; Cheng et. al, 1990 and Haroda et. al., 1996). Presently, it is most popular and large numbers of full scale reactors are used for treatment of wastewater by food and breweries industries (Cheng et.al, 1990; Lettinga and Hulshoff Pol, 1992; Fang et. al, 1994; and Barber and Stuckey, 1999). The success of the UASB reactor depends on the formation of active and settle-able granules (Fang et. al., 1994). These granules consist of aggregation of anaerobic bacteria's self immobilized into compact forms. This enhances the settle-ability of the biomass and leads to an effective retention of bacteria's in the reactor (Mc Carty and Smith, 1986 and Yan and Tay, 1997).

Mesophilic digestion processes for distillery spent wash can be achieved within the temperature range of around 20 ^{0}C, but the optimum temperature is 25-40 ^{0}C, whereas, thermophilic anaerobic digestion can be achieved with in the range of 55-60 ^{0}C (Basu, 1975).

Materials and Methods

The present study was carried out on plant scale to determine the working efficiency of anaerobic treatment of distillery wastewater from a batch fermentation based distillery using molasses as raw material in Uttar Pradesh, India for six months from September, 2003 to February, 2004. Anaerobic treatment was carried out in three mesophilic UASB reactors R_1, R_2 and R_3 and one down flow thermophilic reactor R_4. Reactor R_1, R_2 and R_3 were operated from September to December, 2003 on continuous mode, whereas, from January to February, 2004 only reactor R_1 and R_2 were operated in batch mode. Reactor R_3 was not in operation in the months of January and February, 2004 because flow of reactor R_3 was diverted to reactor R_4.

Reactor

Up-flow anaerobic sludge blanket (UASB) mesophilic reactors made up of reinforced cement concrete (RCC) were in operation previously and thermophilic down flow reactor was commissioned during the study period and the performance of this reactor was measured when it reached at a loading rate of above 60,000 kg COD /day (603 m^3/day of spent wash).

Mesophilic UASB Reactors

Reactor R_1 and R_2 have same design parameters, while R_3 has a large volume than R_1 and R_2.

Design Parameters of Reactors R_1, R_2 and R_3

Reactor R_1 and R_2 - Volume – 2500 m^3, Dia – 23.5 meters, height – 6.5 meters and Treating capacity – 300 m^3.

Reactor R_3 - Volume – 3000 m^3, Dia – 26 meters, height – 6.5 meters and Treating capacity – 360 m^3.

From distillery, the spent wash was sent to the cooling towers and then was collected into buffer tank (acidogenic reactor). Here spent wash was diluted to predetermined value and pH was maintained between 6.5-7.0. Subsequently, it was fed to the reactors with the help of suitable pipeline. A part of effluent (over flow) was recycled continuously to maintained pH and for proper recovery of biogas. Reactor temperature and pH were maintained between 37 ^{0}C to 38 ^{0}C and 7.5 to 7.8, respectively.

Thermophilic Reactor (R_4)

A down flow thermophilic reactor (R_4) made up of mild steel was commissioned during study period. The design parameters of the reactor were as follow: Total Volume – 12560 m^3, Area – 1256 m^2, Central Clarifier – 1050 m^3, Actual Reactor Volume – 11510 m^3 and Treating Capacity – 1100 m^3.

Reactor R_4 was having a central clarifier (cone shaped) for collecting over flow of the reactor with above mentioned volume capacity. A desludging line was provided for removal and addition of extra sludge in the reactor. Reactor was having 4 sampling points with 6 sampling ports each.

Gasholder

Two gas holders each with the volume of 619 m^3 were provided for all three UASB reactors. Thermophilic reactor had a gas dome on the top of the reactor. From the dome, gas was passed to the gasholder having capacity of 1668 m^3 from where the gas was sent to boiler for steam generation by boosters fan.

Sampling and Analysis

Chemical analysis has been conducted both for the feed and effluent on daily basis. All the parameters of the influent and effluent were analyzed by using standard methods for the examination of water and wastewater (Franson et. al., 1995) except pH, Methane (CH_4) Content (%) and Gas Production (m^3/day). pH was measured by using Digital pH Meter. Gas Production was measured by using Gas Flow Meter.

Methane Analysis

CH_4 was measured by using Orsat Appratus. The gas was allowed to enter the orsat apparatus by opening the knob into into the graduated burette through main tube. The opening to the tube filled with 2% boric acid was opened after setting zero and the bottle was moved up and down for about 10 to 12 times so that water pushed the gas into the tube and agitated properly. This allows boric acid to absorb the ammonical nitrogen content from the gas. Again, the bottle was placed to its original position and the rise in the water level in the burette was recorded. This rise indicated the amount of ammonia present in the biogas. Similar procedure was followed of NaOH (10%) tube and the rise in the water level indicates the amount of carbondioxide preset in the gas. The remaining empty space above the water level after completion of the above two processes gave the methane content of gas.

Results and Discussion

In the present study, anaerobic treatment of distillery wastewater (spent wash) was carried out on plant scale. Spent wash is characterized by high temperature (80-90^{0}C), low pH (4.0-4.5), dark brown colour, jagerry odor, high BOD (45000-60000 mg/l) and high COD (80000-120000 mg/l).

Table 1 Performance of UASB Reactors R_1 and R_2 for Six Months (from September, 2003 to February, 2004) and R_3 for four Months (From September to December, 2003)

Reactor Number		pH	Temp (^{0}C)	VFA/ ALK Ratio	OLR (kg COD/ day)	Outlet COD (kg/day)	COD Reduction (%)	HRT (days)	VSS/ TSS Ratio	CH_4 (%)
R_1	Max.	7.9	38.0	0.769	22227	11882	84.9	15.3	0.65	65.0
	Min.	7.5	36.0	0.238	8393	2203	34.5	4.9	0.49	52.0
	Mean	7.67	36.9	0.398	15342	5115	66.4	9.1	0.56	60.1
	S.D.	0.096	0.356	0.143	2691	1557	8.81	1.49	0.038	2.8
R_2	Max.	7.9	37.5	0.909	23809	13543	81.4	20.8	0.63	67.0
	Min.	7.5	36.0	0.232	9662	2539	25.4	4.2	0.48	52.0
	Mean	7.68	36.9	0.448	15314	5739	62.6	10.6	0.54	60.2
	S.D.	0.083	0.313	0.170	2559	2243	12.4	3.6	0.030	2.8
R_3	Max.	7.9	37.5	0.909	30975	16507	89.1	15.8	0.60	67.0
	Min.	7.5	36.5	0.222	11466	1890	25.8	5.3	0.46	54.0
	Mean	7.72	36.9	0.441	20806	6860	66.5	10.5	0.52	60.7
	S.D.	0.086	0.288	0.188	3809	3044	14.6	2.1	0.030	2.06

The present study was carried out for routine operation for six months period covering winter and summer seasons. Monitoring was done on daily basis for different parameters i.e. pH, Temperature, Volatile Fatty Acid (VFA)/Alkalinity (ALK) ratio, Chemical Oxygen Demand (COD) reduction, Volatile Suspended Solids (VSS)/ Total Suspended Solids (TSS) Ratio, Biogas Production, Methane Content, Organic Loading Rate (OLR) and Hydraulic Retention Time (HRT). The results of mesophilic UASB reactors R_1 and R_2 for the months of September, 2003 to February, 2004 and R_3 for the months of September to December, 2003 are given in table- 1 and 2. While the results of thermophilic reactor R_4 is given in table- 3.

Table 2 Overall Performance of the three UASB Reactors (R_1, R_2 and R_3)

	pH	Temp. (^{0}C)	VFA/ ALK Ratio	OLR (kg COD/ day)	Outlet COD (kg/day)	COD Red. (%)	HRT (days)	VSS/ TSS Ratio	Biogas Production (m^3/day)	CH_4 (%)
Max.	7.90	38.0	0.909	30975	16507	89.1	20.8	0.63	23457	67.0
Min.	7.50	36.0	0.222	8393	1890	25.4	4.2	0.49	8330	52.0
Mean	7.69	36.9	0.427	16655	5774	65.0	10.0	0.56	16832	60.3
S.D.	0.092	0.665	0.166	3768	2341	11.9	2.76	0.31	3158	2.7

pH

The pH is an important parameter for stabilizing the anaerobic digestion process, as it affects the microbial activity especially of the anaerobes. The optimum pH range for methane production lies between 7.0-7.5. Methane production decline rapidly at pH below 6 and above 8 (Vlissidis and Zouboulis, 1993). pH was analyzed on daily basis and overall average values of results are shown in figure 1 for all the reactors. pH of spent wash in buffer tank and overflow of reactors before feeding in reactors was measured daily. pH of spent wash in buffer tank was maintained between 6.5-7.0 by adding lime, so that pH should be above 7.5 in all the reactors. From table 1-3 it can be seen that all the pH values fell within the optimum range of gas production.

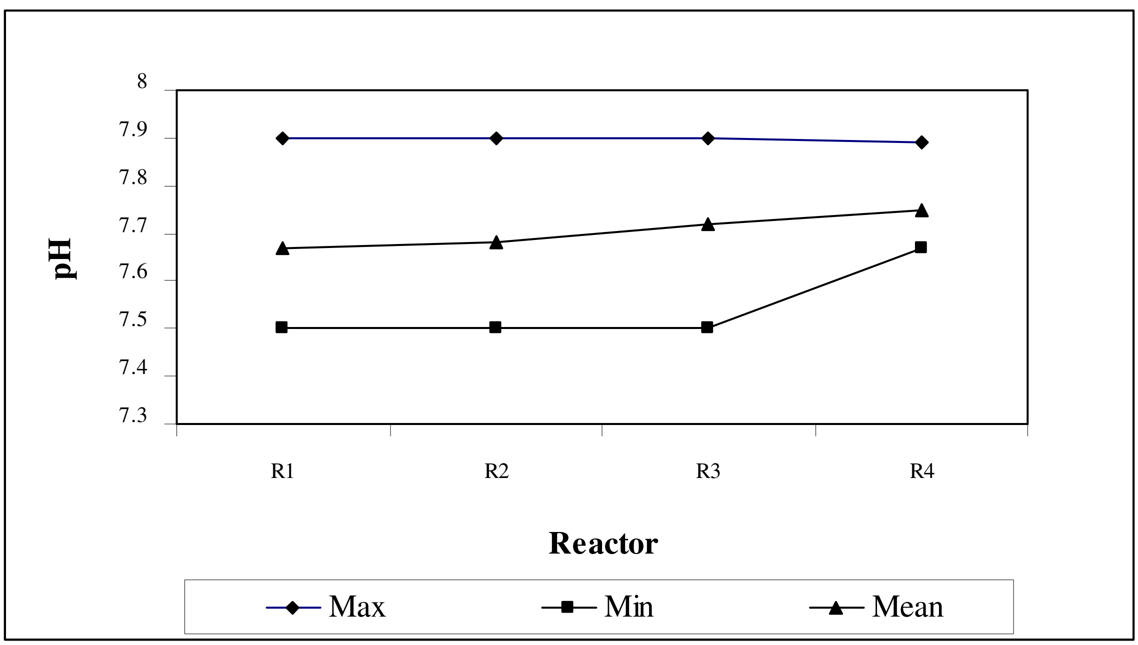

Figure 1 Overall average pH in R1, R2, R3 and R4 reactor.

Table 3 Performance of Thermophilic Down Flow Reactors R_4 for the Months of January and February, 2004 and Overall Average of January and February, 2004

Month	Jan.				Feb.				Jan. & Feb.			
	Max.	Min.	Mean	S.D.	Max.	Min.	Mean	S.D.	Max.	Min.	Mean	S.D.
pH	7.89	7.67	7.75	0.052	7.86	7.67	7.76	0.038	7.89	7.67	7.75	0.046
Temp (^{0}C)	55.6	51.1	52.7	1.027	55	51.6	53.5	0.918	55.6	51.1	53	1.041
VFA/ALK Ratio	0.37	0.121	0.291	0.043	0.454	0.312	0.372	0.032	0.454	0.121	0.33	0.055
OLR (kg COD/day)	92876	51480	72833	9818	96730	59085	79773	10954	96730	51480	76187	10872
Outlet COD (kg/day)	30206	14059	20536	3872	35712	19305	28277	4222	35712	14059	24278	5594
COD Red. (%)	78.7	67.4	71.8	2.84	67.6	58.1	64.5	2.14	78.7	58.1	68.3	4.46
HRT (days)	19.6	12.7	15.7	1.9	18.8	11.8	14.3	2.07	19.6	11.8	15	2.11
VSS/TSS Ratio	0.47	0.38	0.43	0.02	0.42	0.33	0.36	0.021	0.47	0.33	0.4	0.038
Sulphide (mg/l)	1148	740	913	132	1525	1050	1376	138	1525	740	1137	269
Biogas Production (m^3/day)	36505	18437	30358	5327	35683	25210	29446	2762	36505	18437	29917	4273
CH_4 Content (%)	65	58	62.3	1.64	65	54	57	2.56	65	54	59.8	3.4

Temperature

Microbial degradation of organic matter under anaerobic condition is temperature dependent and gas production can take place over a wide range of temperature (4-60 ^{0}C). Higher the temperature, higher will be the microbial activity until optimum range is reached. A further increase in temperature beyond optimum value results in decrease in microbial activity. The optimum temperature for growth of microorganisms is 35 ^{0}C or greater. The rate of gas production has been reported to change from 100-400% for a 12 ^{0}C increase in temperature (Stevens and Schulte, 1979). At temperature 40-45 ^{0}C, the microbial activity is significant, but due to high decay rate, the yield coefficient of methanogenic bacteria approaches zero and thus render continuous operation difficult at that temperature (Vander Berg, 1977).

In figure 2 the measured temperature values for all the reactors are presented. The overall average temperature values for all three UASB reactors R_1, R_2 and R_3 were 36.9 ^{0}C. The higher temperatures resulted during the summer months when ambient temperature was around 40 ^{0}C, whereas lower temperature were observed in winter months when ambient temperature was around 10 ^{0}C. From table 1 it can be concluded that all the values of temperature fell within the optimum range of microbial growth.

Thermophilic processes have a constant rate of methane production which is independent of temperature in the range of 50-70 ^{0}C (Switzeubaum and Jewell, 1980). In reactor R_4, temperature varied from 51.1 to 55.6 ^{0}C with average temperature of 53 ^{0}C (table- 3). When low temperature was observed, additional heating was provided by the steam through a closed steam loop.

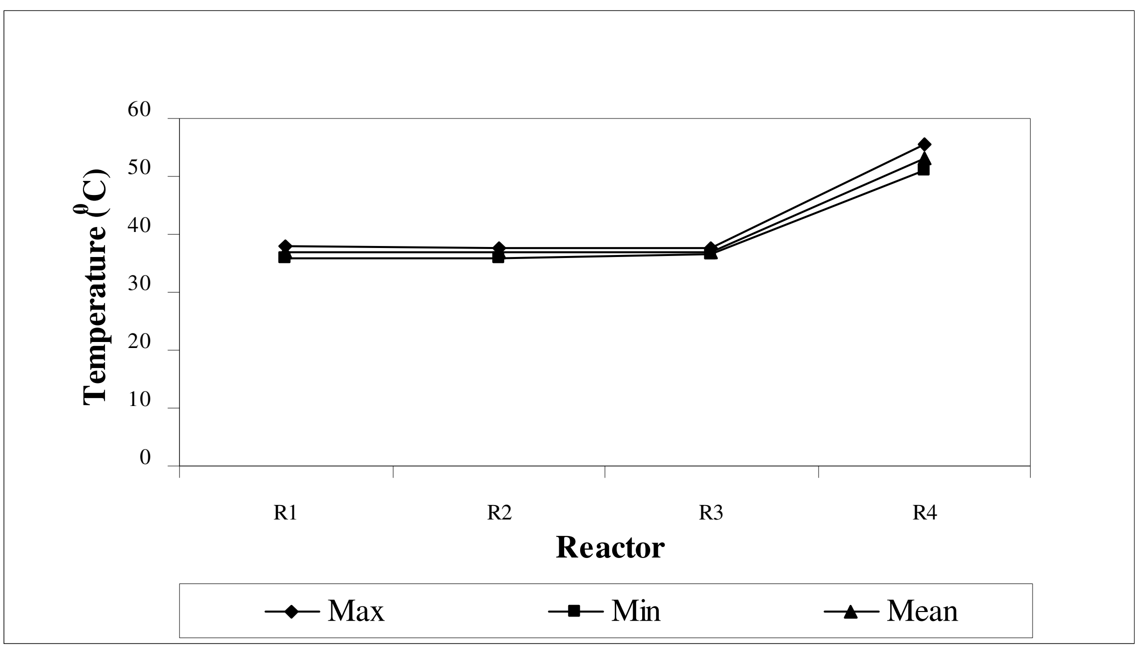

Figure 2 Overall average temperature in R1, R2, R3 and R4 reactor.

VFA/ALK Ratio

The degradation of VFA, the major metabolic intermediate during methanation of complex organic substrates, has been evaluated. The kinetics of acetic, propionic, butyric and valeric acid degradation by the particular microbial ecosystem are of zero order in relation to the substrate and acid degradation rate decreases with increasing length of the acid carbon chain (Segretain and Moletta, 1987). When VFA/ALK ratio is higher than 0.8, the concentration of volatile acids is too high to be equalized by the alkalinity present and unbalanced conditions in the digester usually develop (Vlissidis and Zouboulis, 1993).

Overall average VFA/ALK ratio of all reactors is given in figure 3. The minimum, maximum and average VFA/ALK ratio were 0.238, 0.769 and 0.398 in case of R_1, 0.232, 0.909 and 0.448 in case of R_2 and 0.222, 0.909 and 0.441 in case of R_3, respectively. VFA/ALK ratio around 0.909 was observed only two times in case of R_2 and only one time in case of R_3, throughout the study period. This was due to continuous water washing in these reactors to control the VFA concentration. If VFA/ALK ratio is higher than 0.8 it causes unbalanced conditions in reactor (Vlissidis and Zauboulis, 1993) and ratio of less than 0.4 is good for better performance (Grady and Lim, 1980). Most of the time VFA/ALK ratio was lower than 0.8 which indicate that UASB reactor was working properly.

VFA/ALK ratio lowers than 0.454 with average value of 0.33 was observed in case of reactor R_4, throughout the monitoring period.

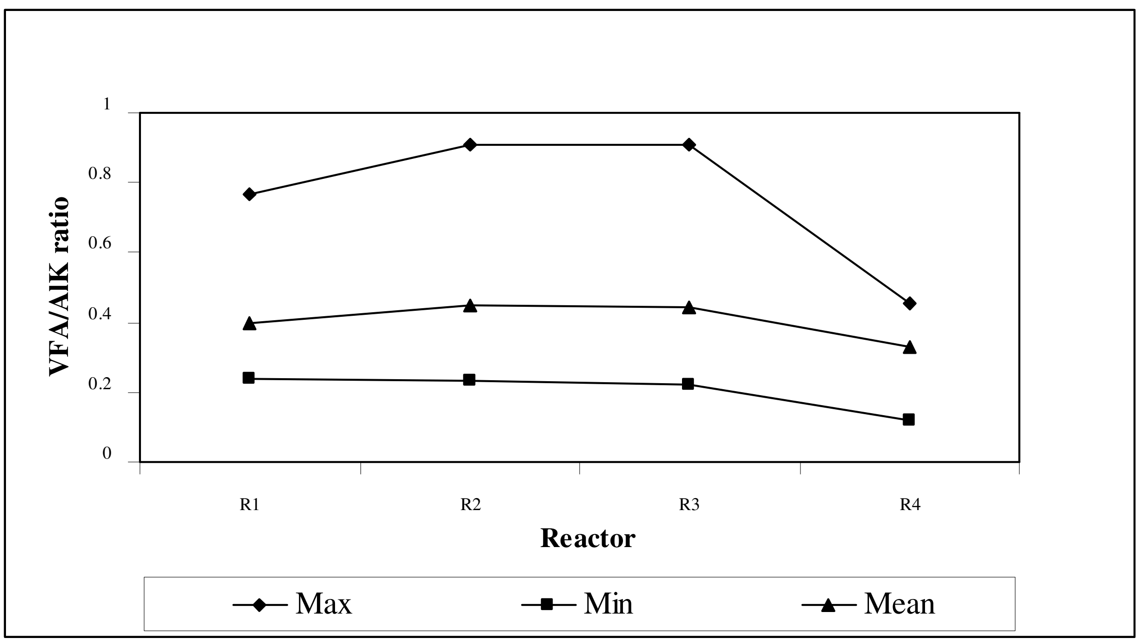

Figure 3 Overall average VFA/ALK ratio in R1, R2, R3 and R4 reactor.

Sludge Profile (VSS/TSS ratio)

It was observed that one kg BOD produces 0.15 kg of TSS. The VSS were assumed to be half of TSS. One kg VSS degrades about 0.45 kg COD, that's why VSS affects the loading rate and COD removal efficiency. VSS/TSS ratio was analyzed on daily basis and overall average results are presented in figure 4. The overall average values of VSS/TSS ratios were 0.56, 0.54 and 0.52 in case of R_1, R_2 and R_3, respectively.

Examined values of sludge profile in R_4 were lower than 0.50 throughout the study period. When VSS/TSS ratio was 0.34 to 0.36, the COD reduction was 61 to 66% and when it was 0.42 to 0.47, COD reduction was 66 to 70%. It indicates that higher the VSS/TSS ratio higher will be the COD removal.

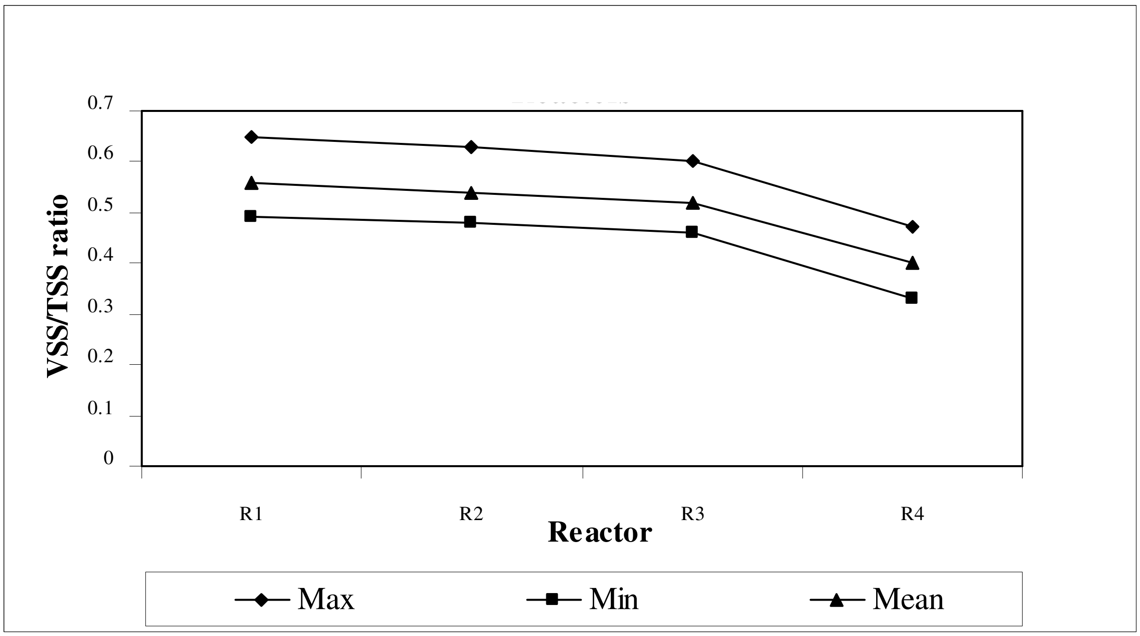

Figure 4 Overall average VSS/TSS ratio in R1, R2, R3 and R4 reactor.

OLR and COD Reduction

Figure 5 shows overall average values of OLR and figure 6 present the overall average values of COD reduction for all the reactors. OLR was between 8393 to 22227 kg COD/day with average values of 15345 kg COD/day in reactor R_1, throughout the study period. The maximum COD reduction was 84.9% at OLR of 14616 kg COD/day with 11.5 days of HRT, whereas minimum COD removal efficiency (34.5%) was observed at OLR of 18144 kg COD/day with 5.4 days of HRT in case of R_1. This lowest reduction rate was observed only once throughout the study period due to unbalanced condition of reactor resulted from shock loading (Goodwin and Stuart, 1994) and low sludge profile. It may also be due to high VFA concentration in the reactor. Goodwin et al. (2001) reported that overall performance of UASB reactor is limited by rate of VFA conversion. The overall average COD reduction in R_1 was 66.4%. In case of R_2, OLR varied from 9662 to 23809 kg COD/day and overall average COD removal efficiency was 62.6%. Maximum COD reduction of 81.4% was observed in R_2 when it was operated at OLR of 14936 kg COD/day and 11 days of HRT, under favourable operating conditions. Minimum COD removal efficiency of 25.4% was observed at a loading rate of 18158 kg COD/day with 4.2 days of HRT. Maximum COD removal efficiency of 89.1% was observed in case of reactor R_3 at a loading rate of 17372 kg COD/day with 15.8 days of HRT. This may be due to favourable operating conditions i.e. higher retention time, 0.55 VSS/TSS ratio etc. Minimum efficiency was found to be 25.8% at 6.5 days of HRT and at a loading rate of 22254 kg COD/day. Lower COD removal efficiencies (from 25 to 38%) were observed in the months of October. This may be due to high VFA/ALK ratio (0.666 to 0.909) and low HRT (6 to 7 days).

It was observed that when R_4 was operated at a loading rate from 51480 to 96730 kg COD/day, COD removal efficiency varied between 58.1 to 78.7%. In reactor R_4 highest COD removal efficiency (78.7%) was observed at OLR of 67942 kg COD/day, HRT 17.1 days, pH 7.69, VFA/ALK ratio 0.277 and sulphide 800 mg/l. Lowest COD removal efficiency was 58.1% and it may be due to higher sulphide concentration (1350 mg/l) and shock loading (82091 kg COD/day). The overall average COD removal efficiency of R_4 was 68.3%.

Biogas Production

Biogas production was analyzed on daily basis. The values shown are for R_1, R_2 and R_3 collectively, because biogas was collected in same gas holder for all the three UASB reactors. Monthly biogas production for reactors R_1, R_2 and R_3 are given in figure 7 and for R_4 in figure 8. Maximum, minimum and average gas production for all the three UASB reactors was 23457 m^3/day, 8330 m^3/day and 16832 m^3/day, respectively, throughout the study period. During the month of January and February, 2004 reactor R_3 was out of operation, so the total gas production for these months should be considered for R_1 and R_2 only. The gas production during January to February, 2004 varied from 9440 to 19896 m^3/day with average value of 12902 m^3/day (0.76 m^3/kg COD). When only reactor R_1 and R_2 were operational in January and February, 2004 average gas production was higher than that of all three reactors, operated during September to December, 2003. It may be due to the fact that reactors R_1 and R_2 were operated in batch mode at slightly lower loading rate, as compared to continuous mode at higher loading rate. It shows that the gas production depends on organic loading rate and mode of operation (batch/continuous).

Gas production in reactor R_4 was between 18437 to 36505 m^3/day with an average value of 29917 m^3/day throughout the study period. Biogas production increases from 18437 to 35497 m^3/day with increase in OLR during the first month, but in the second month it started decreasing at nearly same loading rate and reduced up to 25210 m^3/day at the end of the study period. Possible reason of decrease in gas production in second month of the study may be higher concentration of sulphide in the reactor. The toxicity of sulphide depends primarily on the concentration of H_2S as stated by Sarner (1990).

Methane Content

Overall variation in methane content is shown in figure 9 for all the reactors. Average CH_4 content was 60.1%, 60.2% and 60.7% for R_1, R_2 and R_3, respectively.

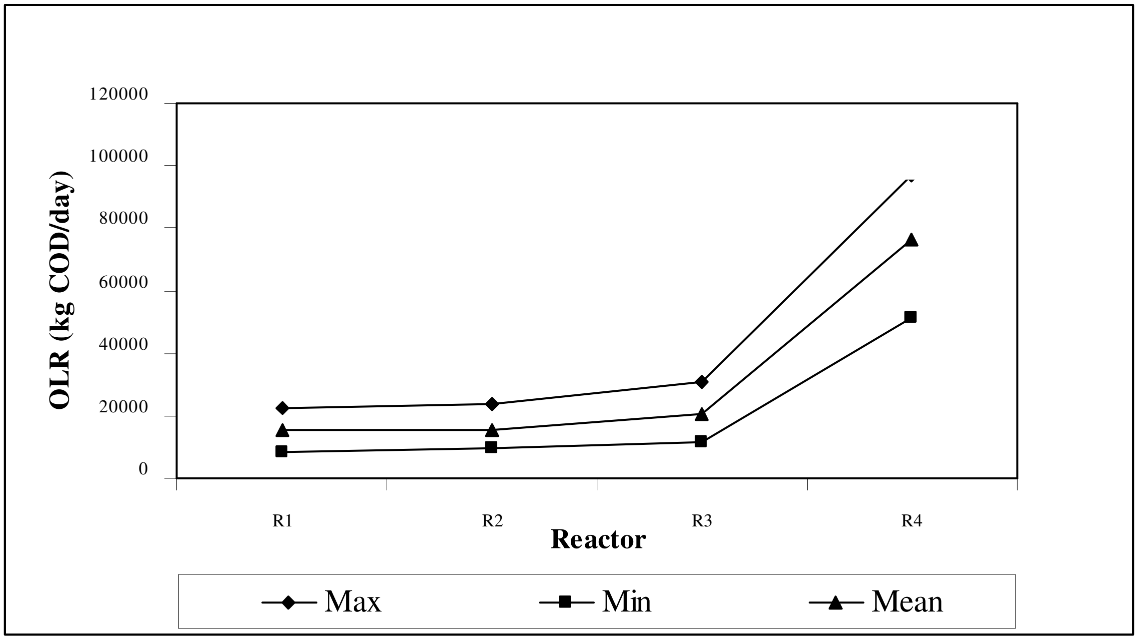

Figure 5 Overall average organic loading rate (OLR) in R1, R2, R3 and R4 reactor.

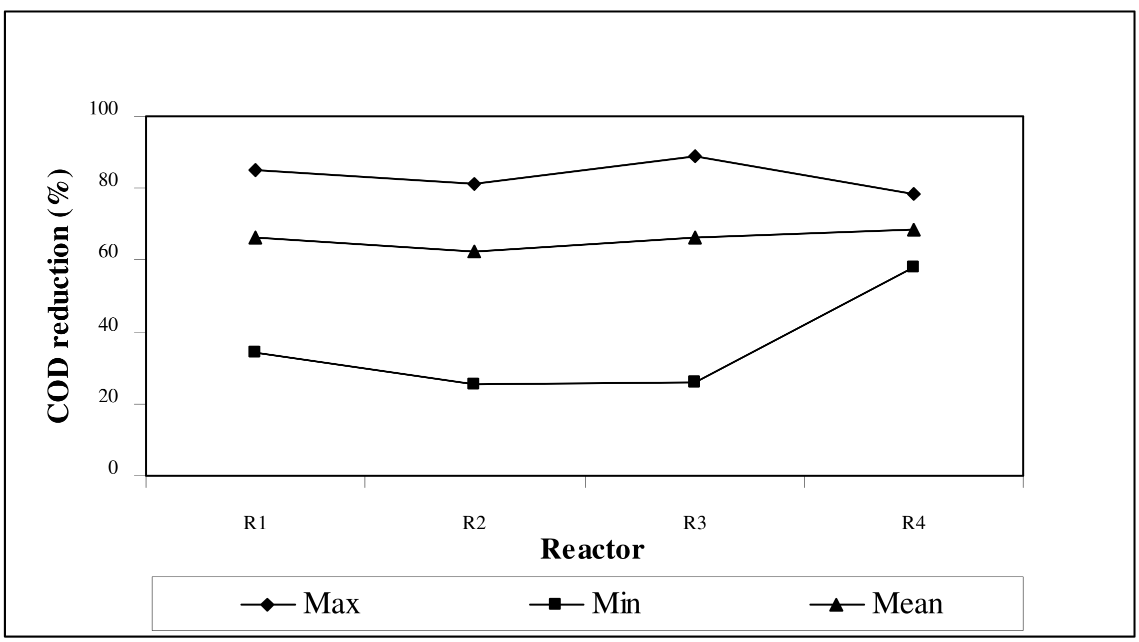

Figure 6 Overall average chemical oxygen demand (COD) reduction (%) in R1, R2, R3 and R4 reactor.

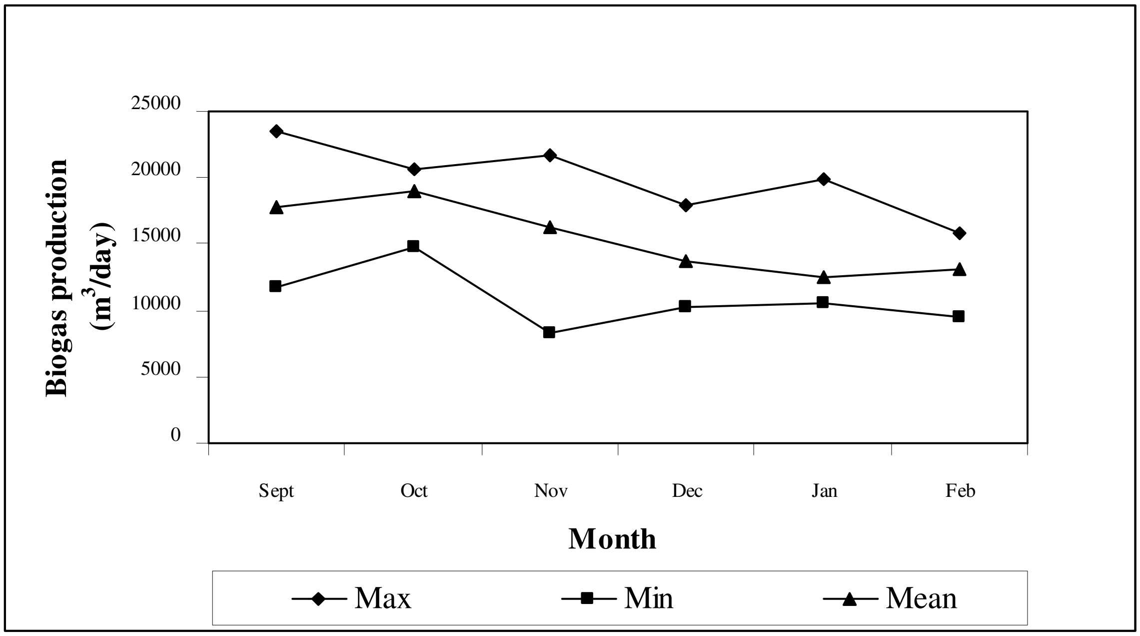

Figure 7 Monthly variation in biogas production in R1, R2 and R3 reactor.

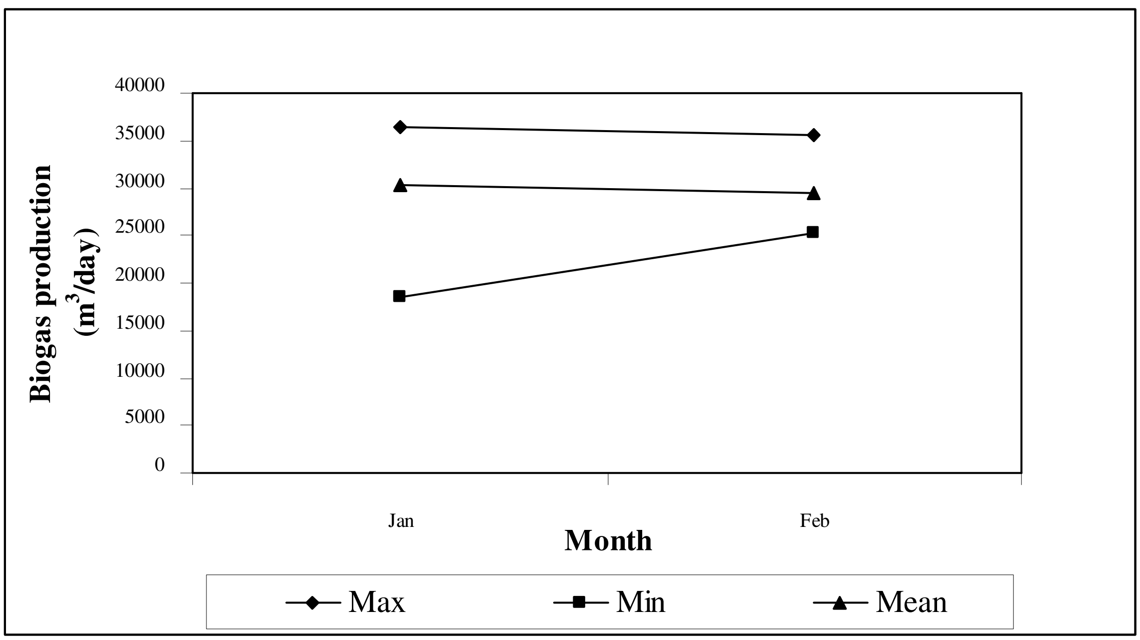

Figure 8 Monthly variation in biogas production in R4 reactor.

In case of reactor R_4 methane content varied from 54% to 65% with overall average of 59.8% during the study period. From the above values it can also be concluded that CH_4 content was nearly the same in case of mesophilic reactors and thermophilic reactor. It was also observed that in first month average CH_4 content was 62.3%, whereas, in second month it was 57%, in case of reactor R_4. This may be due to high sulphide concentration in second month. Speece and Parkin (1983) found that methane production from an unacclimated batch digester was inhibited by a sulfide level as low as 50 mg of S_2- S per liter.

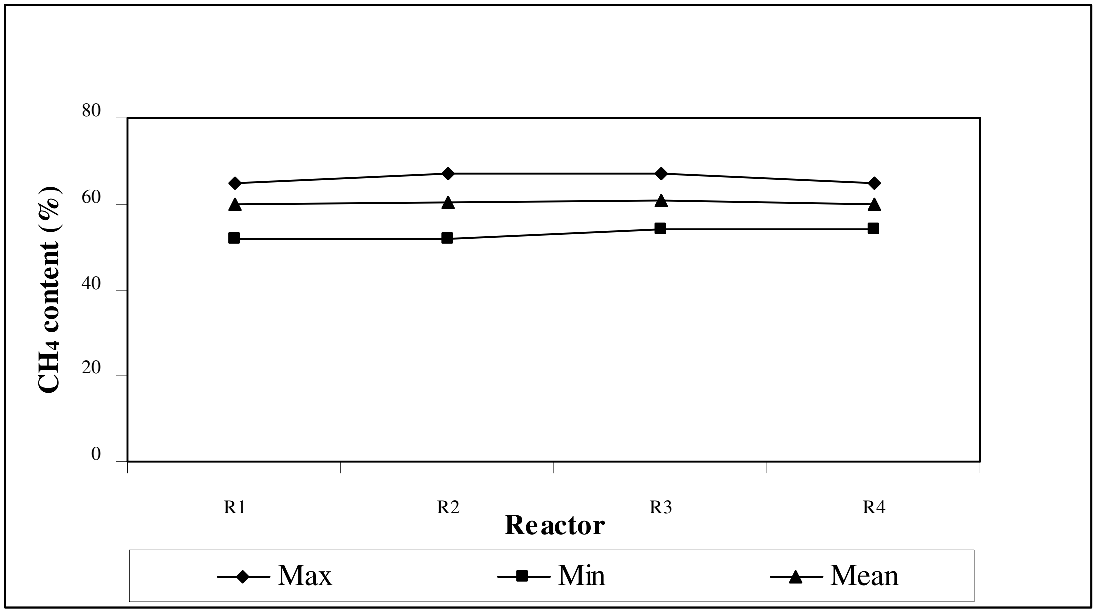

Figure 9 Overall average CH_4 content in R1, R2, R3 and R4 reactor

Sulphide Concentration

Sulphide toxicity in anaerobic digestion is due to free H_2S, which affects the growth of microorganisms (Kroiss and Wabnegg, 1983). The average sulphide concentration in reactor R_4 varied from 740-1525 mg/l. Sulphide concentration in most of the examined values increased with increase in OLR. The present study shows that higher sulphide concentration results in lower gas production as well as methane content.

Relationship Between Different Parameters of Mesophilic and Thermophilic Treatment Process

Correlation coefficient was examined between different parameters on overall average basis for mesophilic UASB reactors R_1, R_2 and R_3 and thermophilic reactor R_4. Overall correlation coefficient for mesophilic reactors is given in table- 4 and for thermophilic reactor in table- 5.

Mesophilic Treatment

I. pH shows significant correlation with CH_4 content and highly significant correlation with inlet COD, COD reduction and HRT and highly significant negative correlation with VFA/ALK ratio.

II. Temperature has highly significant correlation with CH_4 content and significant negative correlation with HRT.

Table 4 Correlation Analysis of Mesophilic Reactors Parameters (R_1, R_2 and R_3) During the Study Period (Six Months)

Parameter	**Temperature**	**VFA/ALK Ratio**	**OLR**	**Outlet COD**	**COD Reduction**	**HRT**	**CH_4**	**VSS/TSS Ratio**
pH	-0.079ns	-0.265**	0.160**	0.041ns	0.162**	0.236**	0.130*	0.066ns
Temperature		-0.063ns	0.104ns	0.010ns	0.077ns	-0.149*	0.179**	0.007ns
VFA/ALK Ratio			-0.123*	0.477**	-0.640**	-0.153**	-0.315**	-0.037ns
OLR				0.447**	0.106ns	-0.332**	0.120*	-0.069ns
Outlet COD					-0.811**	-0.598**	-0.176**	-0.024ns
COD Reduction						0.450**	0.284**	-0.019ns
HRT							0.050ns	0.169**
CH_4								0.012ns
Gas Correlation Analysis	**OLR**	**Outlet COD**	**COD Removal**					
Gas Production	0.651**	0.060ns	0.568**					

Note: *-Significant (<0.05), **-Highly Significant (<0.01), ns -Non Significant (>0.05)

Table 5 Correlation Analysis of Thermophilic Reactor (R_4) Parameters for the Study Period (Two Months)

Parameter	Temp	VFA/ALK Ratio	OLR	Outlet COD	COD Reduction	HRT	CH_4	VSS/TSS Ratio	Sulphide
pH	0.050ns	0.030ns	0.441**	0.403**	-0.243**	-0.396**	-0.041ns	-0.053ns	0.178ns
Temperature		0.197ns	0.424**	0.402**	-0.236ns	-0.467**	-0.413**	-0.366**	0.316*
VFA/ALK Ratio			0.047ns	0.422**	-0.665**	-0.037ns	-0.544**	-0.656**	0.671**
OLR				0.827**	-0.328*	-0.951**	-0.346**	-0.258*	0.264*
Outlet COD					-0.799**	-0.817**	-0.588**	-0.559**	0.618**
COD Reduction						0.365**	0.625**	0.681**	-0.779**
HRT							0.364**	0.287*	-0.296*
CH_4								0.704**	-0.708**
VSS/TSS Ratio									-0.794**
Gas Correlation Analysis	**OLR**	**Outlet COD**	**COD Removal**						
Gas Production	0.610**	0.321*	0.692**						

Note: *-Significant (<0.05), **-Highly Significant (<0.01), ns-Non Significant (>0.05)

III. VFA/ALK ratio shows highly significant correlation with outlet COD, significant negative correlation with inlet COD and highly significant negative correlation with COD reduction , HRT and CH_4 content.

IV. OLR shows significant correlation with CH_4 content, highly significant correlation with outlet COD and highly significant negative correlation with HRT.

V. Outlet COD has highly significant negative correlation with COD reduction, HRT and CH_4 content.

VI. COD reduction shows highly significant correlation with HRT and CH_4 content.

VII. HRT has highly significant correlation with VSS/TSS ratio.

VIII. Biogas production shows a highly significant correlation with inlet COD and COD reduction.

Thermophilic Treatment

I. pH shows highly significant correlation with inlet COD and outlet COD and highly significant negative correlation with COD reduction and HRT.

II. Temperature has significant correlation with sulphide, highly significant correlation with inlet COD and outlet COD and highly significant negative correlation with HRT, CH_4 content and VSS/TSS ratio.

III. VFA/ALK ratio shows highly significant correlation with outlet COD and sulphide and highly significant negative correlation with COD reduction, CH_4 content and VSS/TSSS ratio.

IV. OLR shows significant correlation with sulphide, highly significant correlation with outlet COD, significant negative correlation with COD reduction and VSS/TSS ratio and highly significant negative correlation with HRT and CH_4 content.

V. Outlet COD shows highly significant correlation with sulphide and highly significant negative correlation with COD reduction, HRT, CH_4 content and VSS/TSS ratio.

VI. COD reduction shows highly significant correlation with HRT, CH_4 content and VSS/TSS ratio and highly significant negative correlation with sulphide.

VII. HRT shows significant correlation with VSS/TSS ratio, highly significant correlation with CH_4 content and significant negative correlation with sulphide.

VIII. CH_4 content shows significant correlation with VSS/TSS ratio and highly significant negative correlation with sulphide.

IX. VSS/TSS ratio shows significant negative correlation with sulphide.

X. Biogas production shows significant correlation with outlet COD and highly significant correlation with inlet COD and COD removal.

Conclusions

After through analysis of results, the following conclusions are drawn for smooth operation of mesophilic and themophilic anaerobic treatment.

1. pH should be between 7.6 to 7.7.
2. Temperature should be between 36.9 to 38.0 ^{0}C in case of mesophilic treatment and 52 to 53 ^{0}C in case of thermophilic treatment.
3. VFA/ALK ratio should be between 0.2 to 0.4.
4. OLR should be increased slowly up to optimum range by maintaining pH, temperature and VFA/ALK ratio at above mention values.
5. A balance should be maintained between influent COD and OLR as it effects the COD reduction and gas production.
6. VSS/TSS ratio should be 0.5 or above to achieve maximum gas production and COD removal.
7. Sulphide concentration should be less than 1000 mg/l because at more than 1000 mg/l concentration it have toxic effects and decreases the COD reduction and gas production.
8. Average COD reduction was observed 68.3% in case of thermophilic treatment and 65% in case of mesophilic treatment, whereas gas production was 0.57 m^3/kg COD in case of thermophilic and 0.55 m^3/kg COD in case of mesophilic treatment. So it is better to go for thermophilic anaerobic treatment rather than mesophilic treatment because it is more efficient and has following merits:

   - It has higher efficiency for different OLR as compared to mesophilic treatment.
   - It is flexible and quite stable at OLR and temperature variations and wastewater even having pH 4 can be fed without prior dilution or neutralization.
   - It can be used for high OLR with high COD without pretreatment or water dilution.

Thus from the present study it can be concluded that anaerobic treatment, which not only substantially reduces the organic load of effluent but also produces biogas. Since produced biogas has above 60% methane content, thus it is a valuable fuel. Therefore anaerobic processes have dual advantages of pollution control and production of fuel.

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